

LETTERS

Discovery of an Optical Jet in the Rosette Nebula: Rosette HH2

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Abstract We report on the discovery of an optical jet – Rosette HH2 – in the Rosette Nebula. The jet system bears unique features for residing at the center of a giant HII region, and its energy source is visible with apparently very low extinction along the line of sight. Unlike most other Herbig-Haro jets, this jet indicates a high-excitation origin, and its extended portion shows a seemingly intact structure, instead of normally a shocked working surface, which is attributed to photoablation.

Key words: stars: formation — stars: pre-main sequence — Herbig-Haro objects — ISM: jets and outflows

1 INTRODUCTION

One of the major recent developments in the study of Herbig-Haro (HH) objects has been the discovery of externally irradiated jets within the confines of HII regions (Reipurth et al. 1998). More of such jets immersed in photoionized medium were identified in the Orion nebula and near the late B stars in NGC 1333 (Bally et al. 2000; Bally & Reipurth 2001). The jets discovered by Reipurth et al. (1998) share the following common traits: (a) unlike most of other HH objects, they originate from optically visible young low mass stars, which apparently suffer very low extinction and are not embedded in opaque molecular cloud cores; (b) probably due to impacts from the strong radiation field encountered, the jets are predominantly one-sided or highly asymmetric; (c) as typical HH jets they are of low-excitation origin. However, their spectra resemble more those originating in photoionized gas.

The Rosette Nebula is a spectacular HII region excavated by strong stellar winds from the O stars in the center of the young open cluster NGC 2244, which has an age of about 3×10^6 yrs (Ogura & Ishida 1981). This on-going star forming region (Meaburn & Walsh 1986; Clayton et al. 1998; Phelps & Lada 1997; Li et al. 2002; Li et al. 2003) is located at a distance of ~ 1500 pc at the tip of a giant molecular cloud complex with an extent of around 100 pc (Dorland & Montmerle 1987). In this paper, I shall present the discovery of a second optical jet – Rosette HH2 – embedded in the nebula, which bears exceptionally new features different from other photoionized jets found to date.

2 NARROWBAND IMAGING WITH THE KPNO MOSAIC IMAGER

Narrow band images of the Rosette Nebula were obtained on 1999 March 3 with the Kitt Peak National Observatory 90 cm telescope and the 8k×8k MOSAIC camera (Muller et al. 1998). The images were taken with the $H\alpha$, [OIII] and [SII] filters, with central wavelengths/FWHMs 6569/80, 5021/55, and 6730/80Å, respectively. For each filter, five exposures of 600 seconds were taken, each image slightly offset to fill in the physical gaps between the MOSAIC CCDs. The pixel scale is $0.423'' \text{ pixel}^{-1}$ resulting in a $59' \times 59'$ field of view (Rector 2001, private communications).

3 RESULTS AND DISCUSSION

An optical jet, Rosette HH2, was discovered when scrutinizing the narrow band images of the Rosette Nebula (Fig. 1); as a comparison, the CFHT R band imaging of the same region with comparable spatial resolution is also shown. A unipolar jet with a visible extension of ~ 24 arcsec is believed to have developed from a faint visible star immersed in the HII region excited by the central young cluster NGC 2244. The total projected extent of the Rosette HH2 jet is 0.055 pc or 11423 AU at an adopted distance of 1.5 kpc, which gives a length-to-width ratio of $\sim 9:1$ which is commensurate with that of typical HH jets. The visibility of the star indicates fairly low extinction along the line of sight, which strongly suggests that the young stellar object might have lost its extended envelope albeit a substantial disk still exists, which is large enough to power the detected mass outflow, or otherwise an alternative jet formation mechanism exists due to its photoablated nature in this extreme environment.

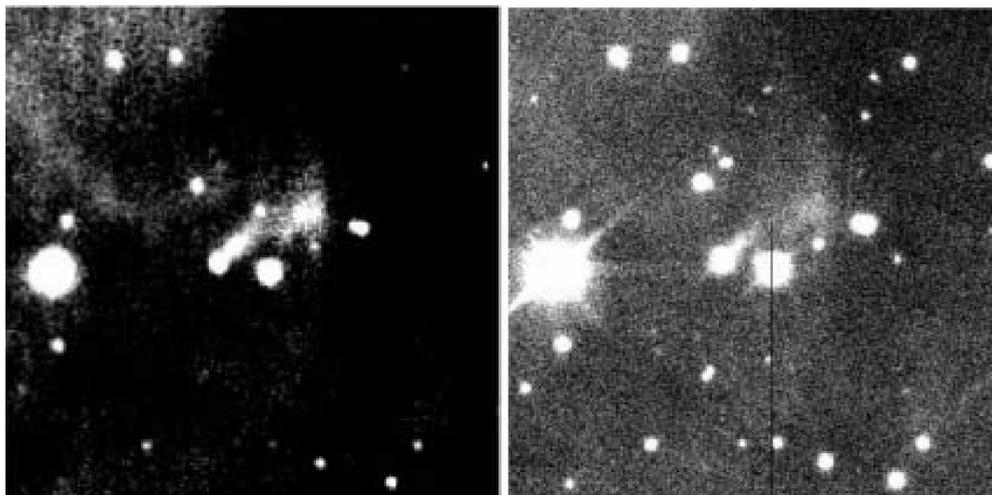


Fig. 1 Left panel: $H\alpha$ imaging of the optical jet ($1.4' \times 1.4'$), north is up and east is to the left. The power source is located at R.A. = $06^{\text{h}}32^{\text{m}}14.14^{\text{s}}$, Dec = $05^{\circ}02' 17.95''$ (J2000), which is probably a T Taur star previously unknown. Right panel: CFHT R band imaging of the same region.

As presented by Figs. 1 and 2, a knotty structure of the jet is clearly seen, an apparent separation of a collimated beam and a more extended portion indicates an episodic eruption of the driving source. However, no apparent counterjet was detected, though the existence of

a faint counterjet cannot be excluded currently due to the large distance of the star formation region as compared to that of the Orion nebula, in the core of which the only parallel jet driving YSOs were found (Reipurth et al. 1998). On the other hand, it is noticed that the extended part of the flow is clearly off-axis (Figs. 2 and 3), perhaps signifying supersonic motion of the energy source across the HII region, merely projection effects or otherwise precession of the disk-jet system. Similar but seemingly less prominent results have also been detected in HH 444 and HH 445 (Reipurth et al. 1998), which could well be due to impacts of stellar winds.

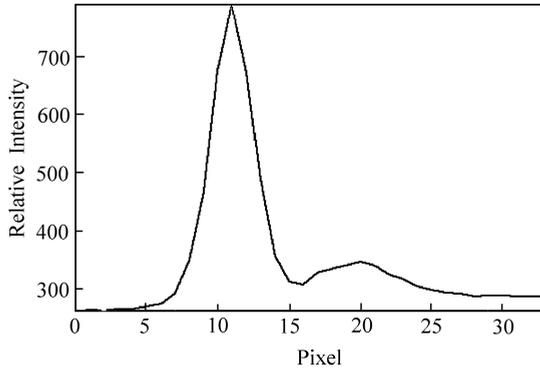


Fig. 2 Intensity of H α emission along the jet direction. Note that the jet is weak at the base, which might indicate that jet eruption in this system could have ceased temporarily or even forever. No evidence for a counterjet can be found.

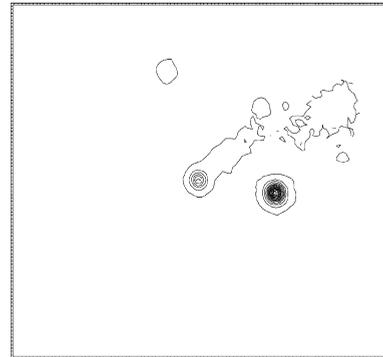


Fig. 3 Contour map of H α emission from the jet. Note the off-axis distribution of the extended portion of the jet.

An interesting finding is that the extension of the Rosette HH2 jet seems to show a surprisingly intact structure instead of the normal bow shocked working surface (Figs. 1 and 3). We thus infer the formation of the jet is possibly after the evacuation of ambient materials by robust stellar winds from the central OB stars. The energy source could have been formed in dense cloud cores or even swept-up cloud materials following the formation of the HII region and is among the very last objects to form. The seemingly intact extension of the jet could otherwise be attributed to its photodissipated nature of the system in such an extreme environment. Being located in an HII region, strong impacts are expected to impress on the disk evolution, mass accretion and the ultimate mass of the infant star, this however seems to have affected not very much the launching of the jet, except that HH jets discovered in HII regions are predominantly monopolar or at most have poorly developed counterjets, which strongly suggests the presence of a relic accretion disk that makes the jet formation and collimation possible. As formerly stated in this section, the photoablated materials in the relic disk could have helped much in the formation of the jet, with a mass loading mechanism much different from typical HH jet systems.

Unlike the irradiated jets discovered in Orion (Reipurth et al. 1998), the Rosette HH2 jet is found to have a high-excitation origin (Fig. 4) as evidenced by the diffuse [OIII] emission. The [OIII] emission probably originated in strong impacts by the UV radiation field of the central OB stars that excited the HII region, as well as less prominent effects from strong stellar winds, the existence of which is indicated by the presence of million degree hot plasmas in the center of the HII region as results of wind shocks (Townsend et al. 2003). Such hot plasmas are not

detected in the Orion Nebula. It is noteworthy that [SII] emission is prominent only at the collimated part of the jet (Fig. 5), though weak emission can also be marginally noticed in its extension, which could be due to internal shocks.

As indicated by Reipurth et al. (1998), the visibility of all the jet material will definitely help toward a more precise determination of the physical parameters of the outflow such as mass loss rates, without facing great uncertainties from current shock models. On the other hand, the excitation state of the photoionized jets offers a new diagnostics of the physical conditions of the photoablating environments in which they are immersed.

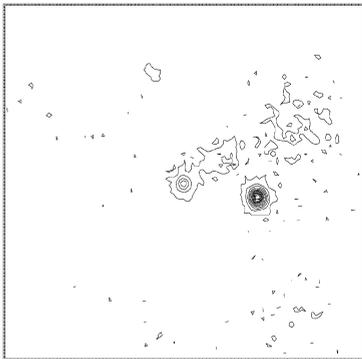


Fig. 4 Contour map of [OIII] emission from the jet. Note the inhomogeneous distribution of the [OIII] emission.

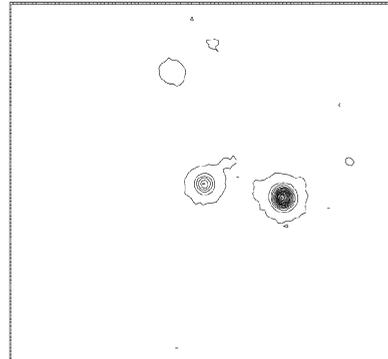


Fig. 5 Contour map of [SII] emission from the jet. Note that weak [SII] emission in the extension of the jet is not shown here.

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